MORPHOMETRIC CHARACTERIZATION OF LUNAR LANDING SITES.

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Introduction: As ambitious surface exploration of the Moon commences in the 2020s, [1], it is important to develop reliable and objective metrics for understanding the quality of future landing sites. A key prerequisite for any exploration and utilization of the lunar surface is a safe landing. One of the most important methods to provide understanding of potential metrics for landing site safety in the lunar context is the systematic comparison of candidate and historic landing sites [2].

The goal of this project is to determine the morphometric parameters of the lunar surface at 16 successful lunar landing sites where adequate data exists to execute a quantitative comparison using various parameters. Quantitative analysis of Lunar Reconnaissance Orbiter (LRO) data should inform mission planning activities by providing morphologic metrics for landing sites including slope, Terrain Ruggedness Index (TRI), and rock abundance

These comparisons will assist mission planners and exploration scientists by providing "calibration points" for using Lunar Reconnaissance Orbiter (LRO) data to successfully plan and execute lunar powered descents in the future. The metrics included in this analysis describe the form of the terrain and can be calculated for any potential future landing site [2, 3].

Another objective of this project is to determine how the derived morphologic parameters for the same landing site change between common pixel scales. In ideal lighting conditions, 2m/px Narrow Angle Camera Digital Terrain Models (NAC DTMs) can be assembled using stereoscopic imagery from two or more concentric orbits of the LRO. However, due to low light conditions near the lunar poles, the highest quality data for many potential lunar landing sites comes from the Lunar Orbiter Laser Altimeter (LOLA). Therefore, we seek to assess how the derived slope and TRI values change as a function of changes in the DTM postings from 2m/px to 5m/px.

Methods and Data: We obtained Narrow Angle Camera (NAC) Digital Terrain Models (DTMs) for 16 regions corresponding to historical lunar landing sites from NASA's Planetary Data System, 12 of which were available in 2m/px pixel scale. The elevation data that is used in the analysis of each site is a circle with a 100m radius, centered on the landing module. We verified the positional accuracy of the landing module by using high resolution orthophotos of each site to align the precise coordinates of the landing module and register datasets using that location as a central control point.

Slope and TRI are derived from elevation data [7] and rock abundance comes from LRO Diviner surface temperature data [8]. We generated maximum, minimum, average, and standard deviation values for slope data derived using the Horn and 4-corners algorithms and obtained these values for TRI data derived using the Wilson algorithm [7].

Each DTM has a corresponding confidence map that outlines which pixels may not have completely accurate values. We used the "extract by mask" tool in ArcGIS Pro to reduce the confidence map to the 100m radius surrounding the landing module and recorded the concentration of low-confidence pixels as a percentage of the total pixels in the sample area.

To assess the average quantitative differences between the common LRO DTM pixel scales and to serve as an analogue for the LOLA elevation data available for the Artemis Polar Exploration Zone [6] we resampled the NAC DTMs and calculated the absolute difference of the average values between the 2m/px and 5m/px data for slope and TRI.

The initial slope calculation for this analysis was performed using the "Eight-Neighbor" Horn algorithm. Since it is not the only algorithm that is commonly used, we derived slope data using the "4-Corner" Zevenbergen-Thorne method as well to assess the potential difference between commonly employed methods of calculating slope [10]. We imported the global lunar rock abundance data to ArcGIS Pro and identified the rock abundance value for each landing site coordinate following manual geolocation. Lastly, we resampled the Apollo 11 landing site DTM incrementally between 2m-45m and generated slope and TRI values for each pixel scale to observe how the metrics trend.

Results: The morphometric parameters for the successful lunar landing sites in this analysis are:

- **Slope (2m/px): ≤ ~8.39°**
- **TRI (2m/px): ≤ ~0.23 m.**
- **Rock Abundance: ≤ 0.015**

The average difference between the 2m/px and 5m/px resolution derived datasets are:

- **Slope: ~0.28°**
- **TRI ~0.19 m.**

The average percentage of low confidence pixels in the cropped landing site DTMs is **~6.85%**, and the difference between the Horn and 4-Corner methods' average slope value is **~0.03°**

Discussion: The results of this analysis improve upon previous results and offer a basis for comparison for potential future missions. Our analysis demonstrates that as DTM pixel scale decreases from 2 to 45 m, observed slope values may slightly decrease, and TRI values increase. The margin of observed differences is relatively small between 2m/px and 5m/px, increasing confidence that 5m/px DTMs can be successfully employed when NAC-derived 2m/px models are not available.

The pixel scale of the rock abundance dataset (236 m/px) is much larger than the pixel scales of NAC DTMs; an entire landing site sample area fits well within a single rock abundance pixel. The rock abundance metric has been recorded as a single value for each site instead of an average from a larger dataset. The metric is useful for assessing the probability of subpixel hazards, not for revealing where those subpixel hazards are [8]. Subpixel hazards can be mitigated through the analysis of rock abundance, in tandem with hazard detection systems as a landing module approaches the lunar surface [9].

The average low confidence pixel percentage of ~6.85% does not mean that 6.85% of the DTM pixel values are wildly incorrect. Instead, this percentage is representative of the number of pixels that could be off slightly due to various limitations of the DTM production process [4]. Lastly, the average difference between the Horn and 4-corner methods of .03° means that the two slope algorithms are practically interchangeable.

Conclusions: The metrics recorded for the 16 successful lunar landing sites in this analysis reflect qualities of the lunar surface that are relevant for ensuring successful lunar landings and can inform mission planning activities in the future. Although higher quality data is always desirable, it isn't always realistically available. As such, the fact that the 2 m/px and 5 m/px datasets produce similar results indicates that morphometric analyses using 5 m/px topographic data will provide valuable results for analyzing areas of the lunar surface that lack data with smaller pixel scales.

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References: [1] *Space Policy Directive-1,* (2020). [2] Lawrence, SJ et al. (2020) LPSC 51, [3] Lawrence, S. J. et al. Lunar Exploration Analysis Group (2015). [4] Henriksen, MR et al. *Icarus*, *283*, 122–137 (2017). [5] Speyerer, EJ. (2016). *Icarus*, *273*, 337–345. [6] Smith, D. E. (2017). Icarus, 283, 70–91. [7] Wilson MFJ et al. (2007) Mar Geo 1-2, 3-35. [8] Bandfield, J. L. (2011) JGR-Planets *116 (2011).* [9] Diego F. Pierrottet et al. (2007) Proc. SPIE 6550, Laser Radar Technology and Applications XII, 655008 (2007). [10] Jones, K. H. (1998) *Computers and Geosciences, 24*(4), 315–323 (1998).

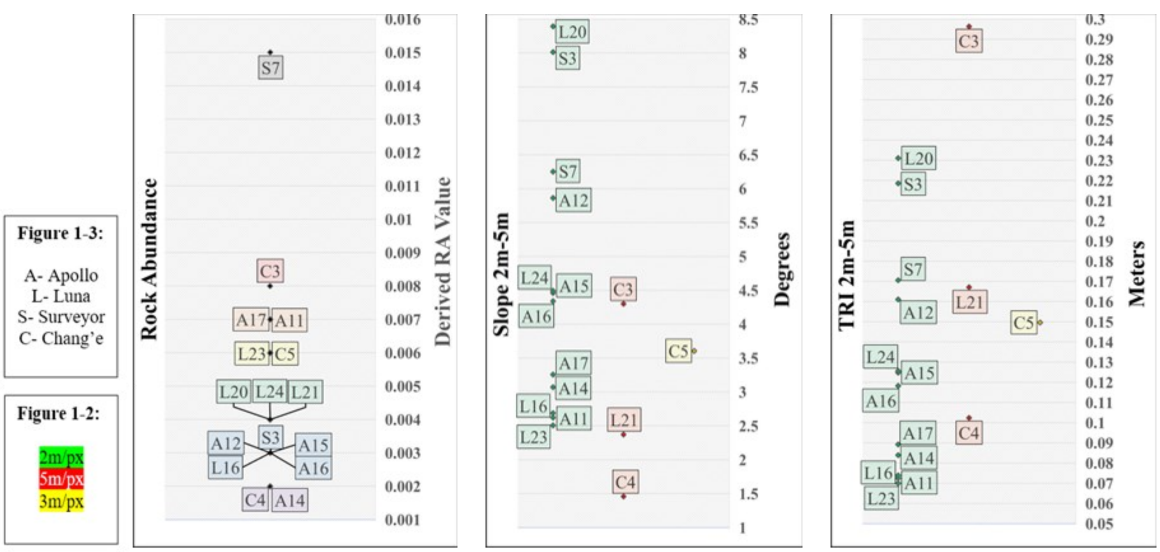

Figure 1. Diviner Rock Abundance from this study.
Figure 2. Slopes used in this study.
Figure 3. Terrain Ruggedness Index for study areas.